Time-domain astronomy with *Fermi* GBM in the Multi-Messenger Era

Colleen A. Wilson-Hodge (NASA/MSFC)
Fermi GBM PI
on behalf of the *Fermi* GBM team

AAS HEAD Sun Valley, ID, Aug 23, 2017

Fermi Gamma-ray Space Telescope

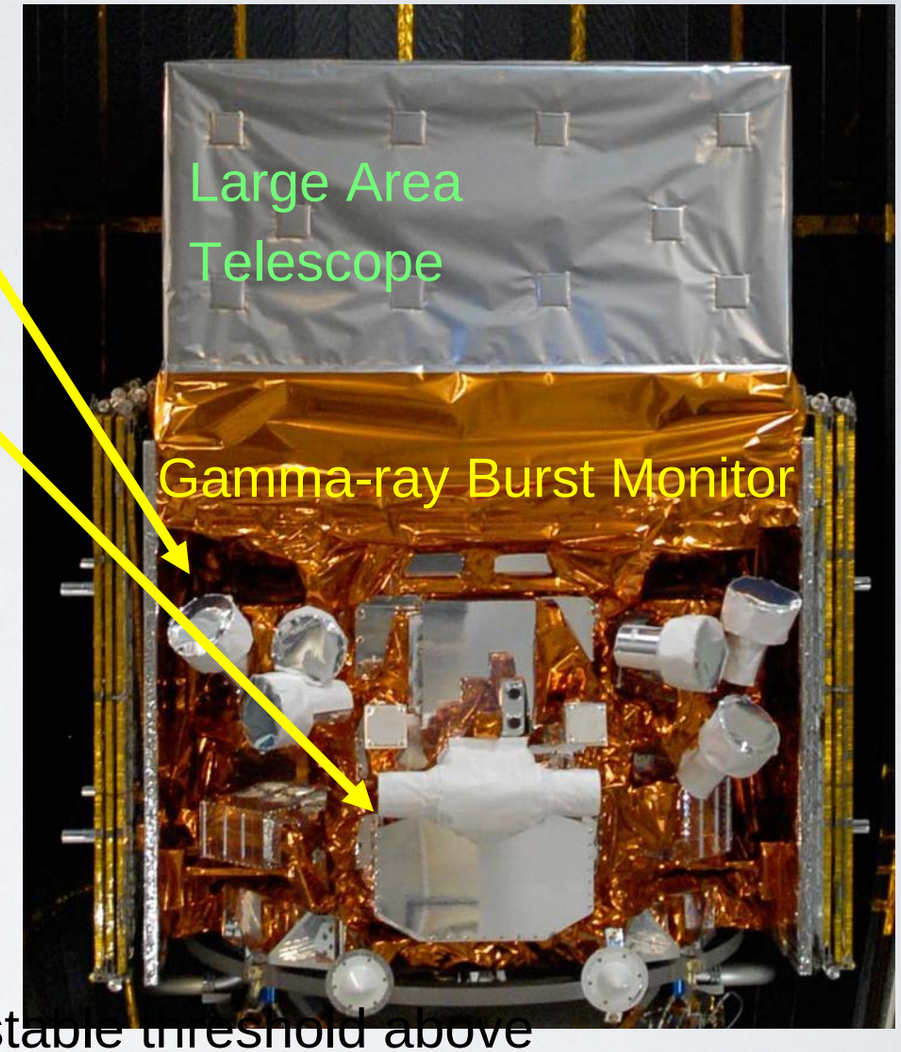
http://gammaray.nsstc.nasa.gov/

GBM:

- FOV >8sr
- Whole sky every ~90min

12 NaI detectors
(8keV—1MeV)

2 BGO detectors
(200keV—40MeV)



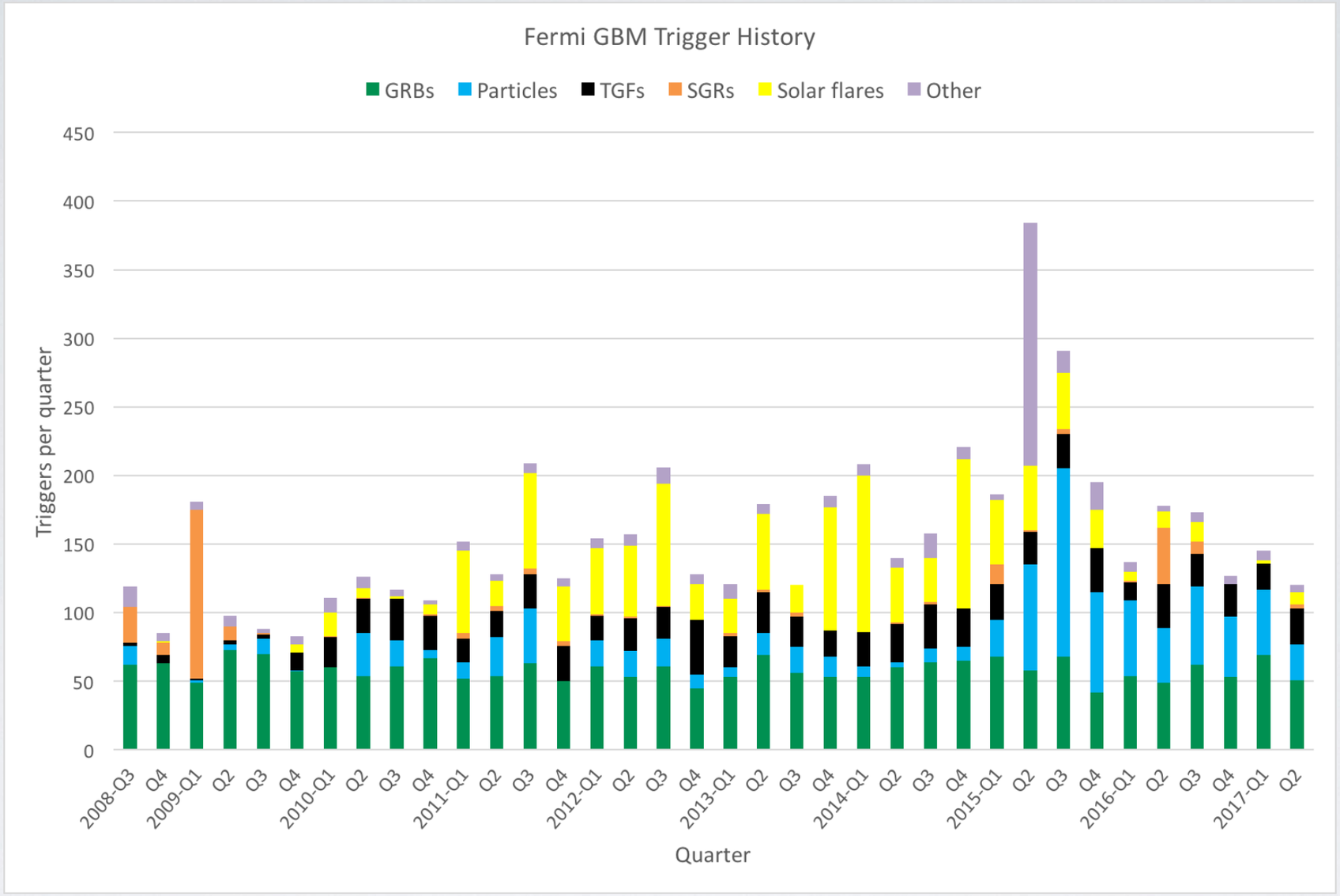
Data products:

- CTIME (continuous high time resolution)
  — 256 / 64 ms, 8 energy channels
- CSPEC (continuous high spectral resolution)
  — 4096 / 1024 ms, 128 energy channels
- TTE / CTTE (time tagged events)
  — 2μs, 128 energy channels

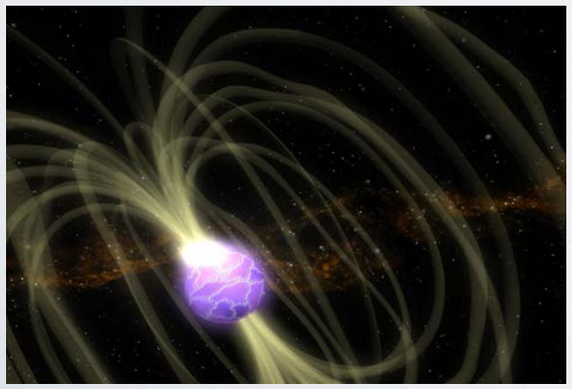
Triggering algorithms:

- In-orbit count rate increase in 2+ NaI detectors above adjustable threshold above background
  - 10 timescales — 16ms up to 4.096s
  - 4 energy ranges — [50-300], [25-50], >100, >300 keV
- Ground-based offline search for rate increase
- Earth occultation
- Pulsar phase folding

Fermi GBM Science

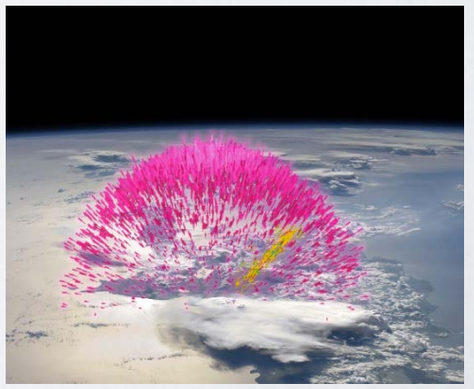


Galactic — pulsars, magnetars

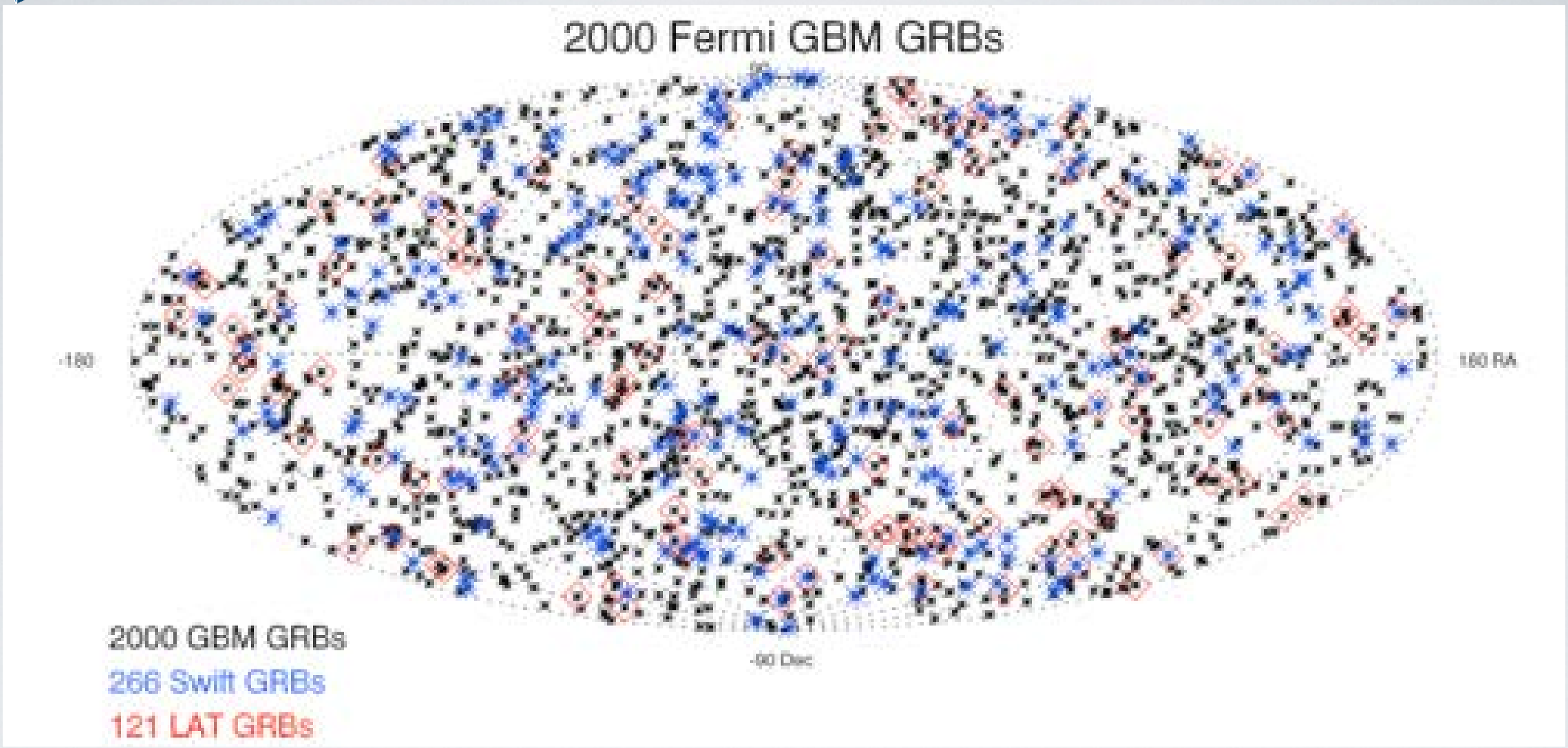


Gamma-Ray Bursts

Terrestrial Gamma-ray Flashes



Gamma-ray Bursts

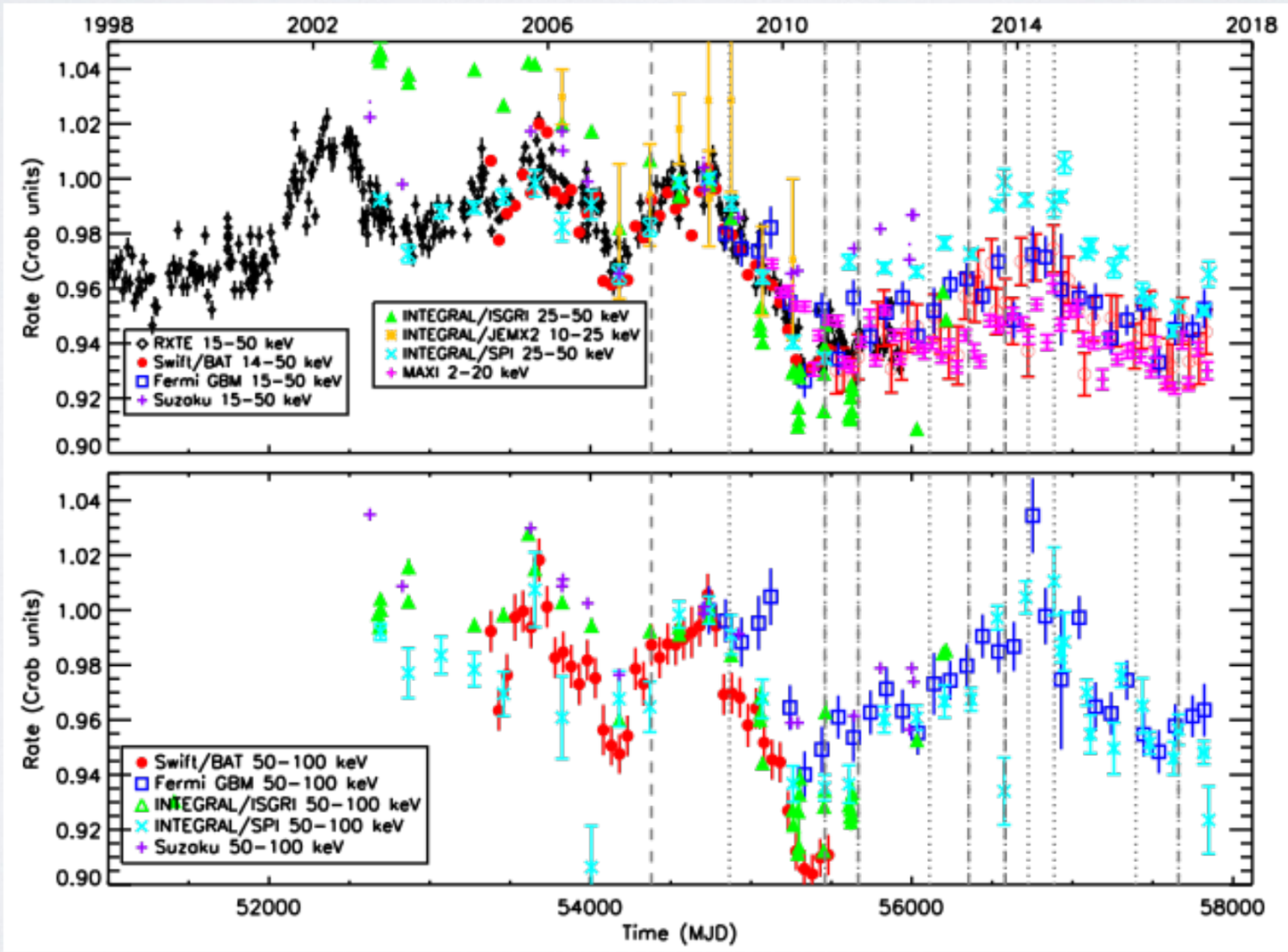


- Over 2000 GRBs have been detected since launching in 2008.
  - 200 long GRBs / year -> massive star collapse.
  - 40 short GRBs / year -> compact merger event.
  - 13% seen by Swift.
  - 52% within *Fermi* LAT FOV, 6% detected.

Monitoring by Earth Occultation technique

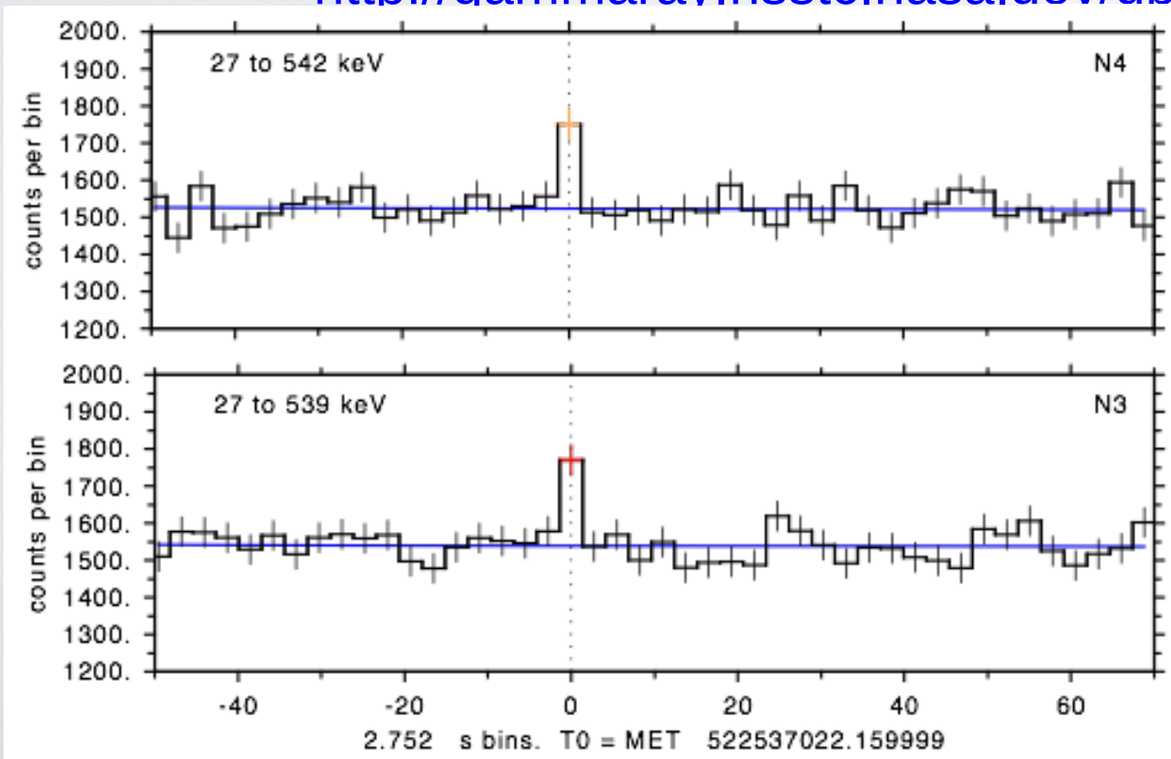
https://gammaray.nsstc.nasa.gov/gbm/science/earth_occ.html

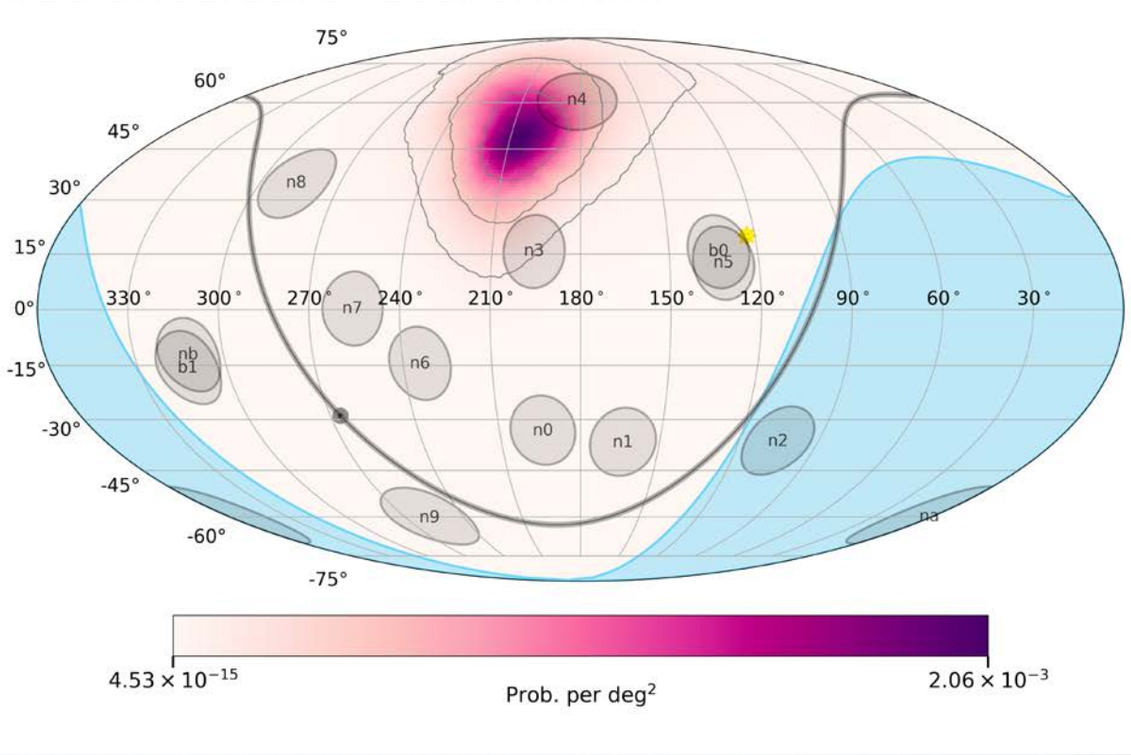
- 200+ sources are monitored from X-ray binaries to Active Galactic Nuclei.
  - 102 detections, 9 at >100 keV.
- Crab Nebula flux variations over the past decade, averaging 10% and up to 40% at 300—500 keV (Wilson-Hodge et al. 2011).
  - Changes in shock acceleration or nebular magnetic field?



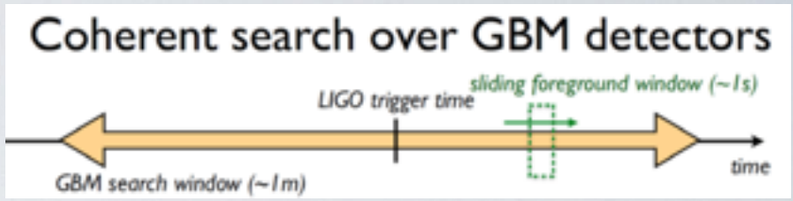
Offline GRB search

- **Untargeted** search in the Continuous Time Tagged Events (CTTE) data.
  - 18 timescales: 64ms to 32 s
  - Four energy ranges
- GCN now available, more info at https://gcn.gsfc.nasa.gov/fermi_gbm_subthreshold.html
  - Currently short timescale pipeline is released, long (2.8+s) pipeline is in progress.
  - Expected rate is ~70/month (during periods of Cyg X-1 activity, it may increase by 4x).
  - Current time delays range from 0.5 to 6 hours due to ground processing and data downlink.
  - Location uncertainties are in the range of 10 to 40 deg (68% containment radius).
  - List of candidates from older data (2013 and on) are available. http://gammaray.nsstc.nasa.gov/gbm/science/sgrb_search.html

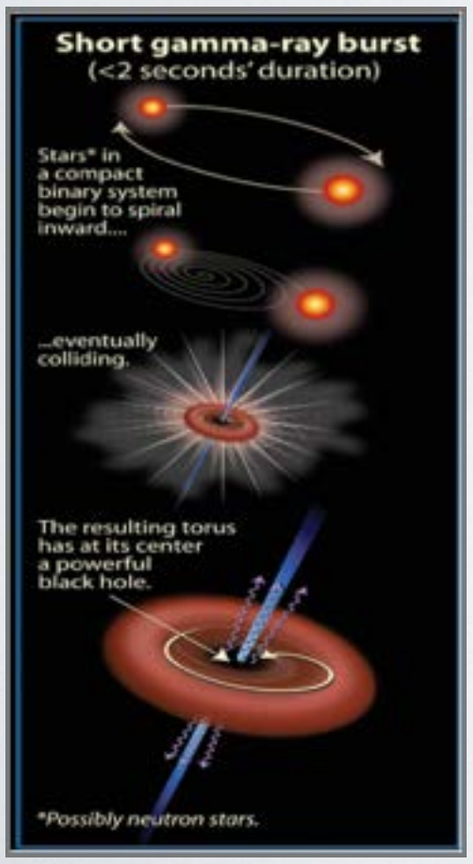




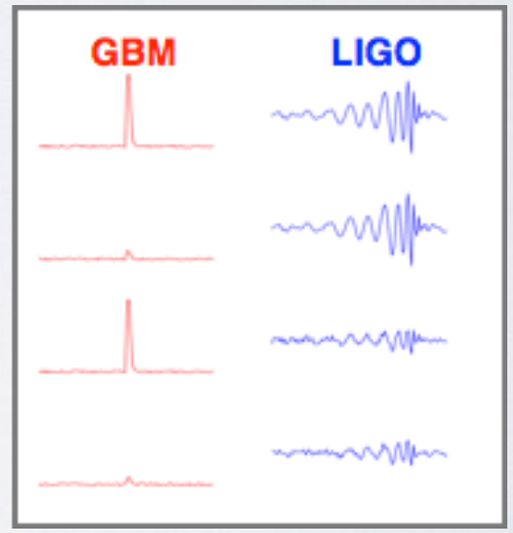
Offline GRB search



- **Targeted** search in the Continuous Time Tagged Events (CTTE) data. (Blackburn et al. 2015, Goldstein et al. arXiv:1612:02395)
  - Looks for coherent signals in all detectors given an input time and optional skymap.
  - Calculate likelihood ratio of source and background.
  - Search +/- 30 seconds of input event time.
  - Sliding timescales from 0.256s to 8s (capable down to 0.064s) with a factor of 4 phase shift.
  - 3 source spectral templates using Band function: soft, normal, and hard.

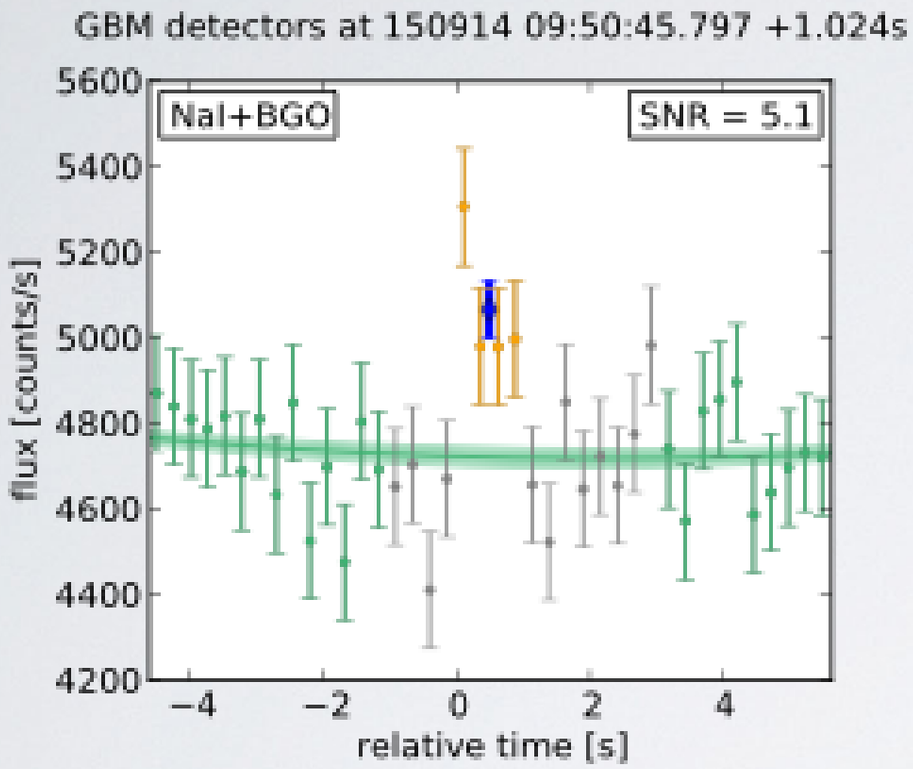


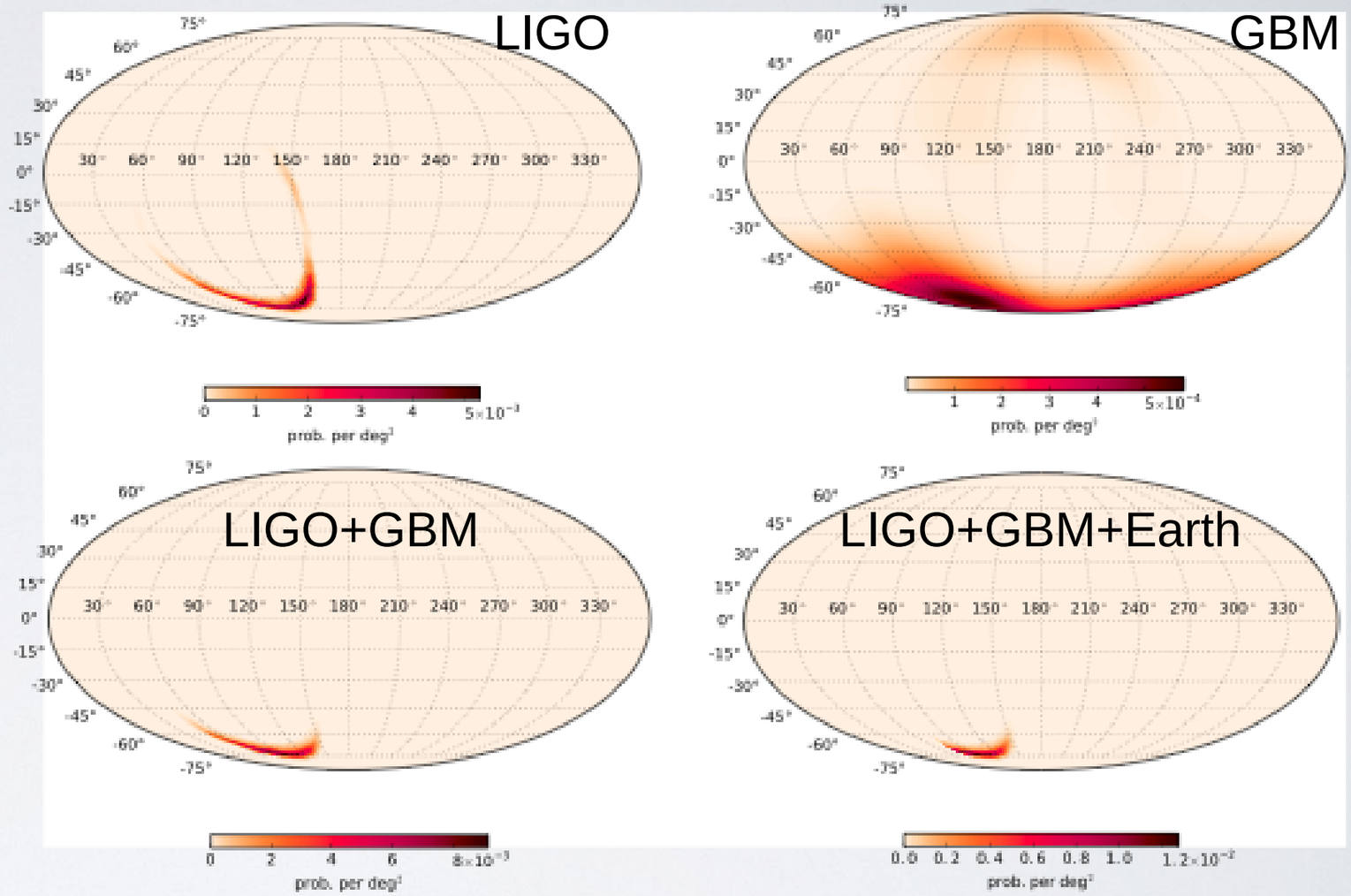
Ideal Scenario	Bright GBM	Bright LIGO
GW150914 Scenario	Sub-threshold GBM	Bright LIGO
Typical more distant short GRB	Bright GBM	Sub-threshold LIGO
Both Sources Faint	Sub-threshold GBM	Sub-threshold LIGO



Follow-up to Gravitational Wave Event GW150914

Connaughton et al. ApJL 2016



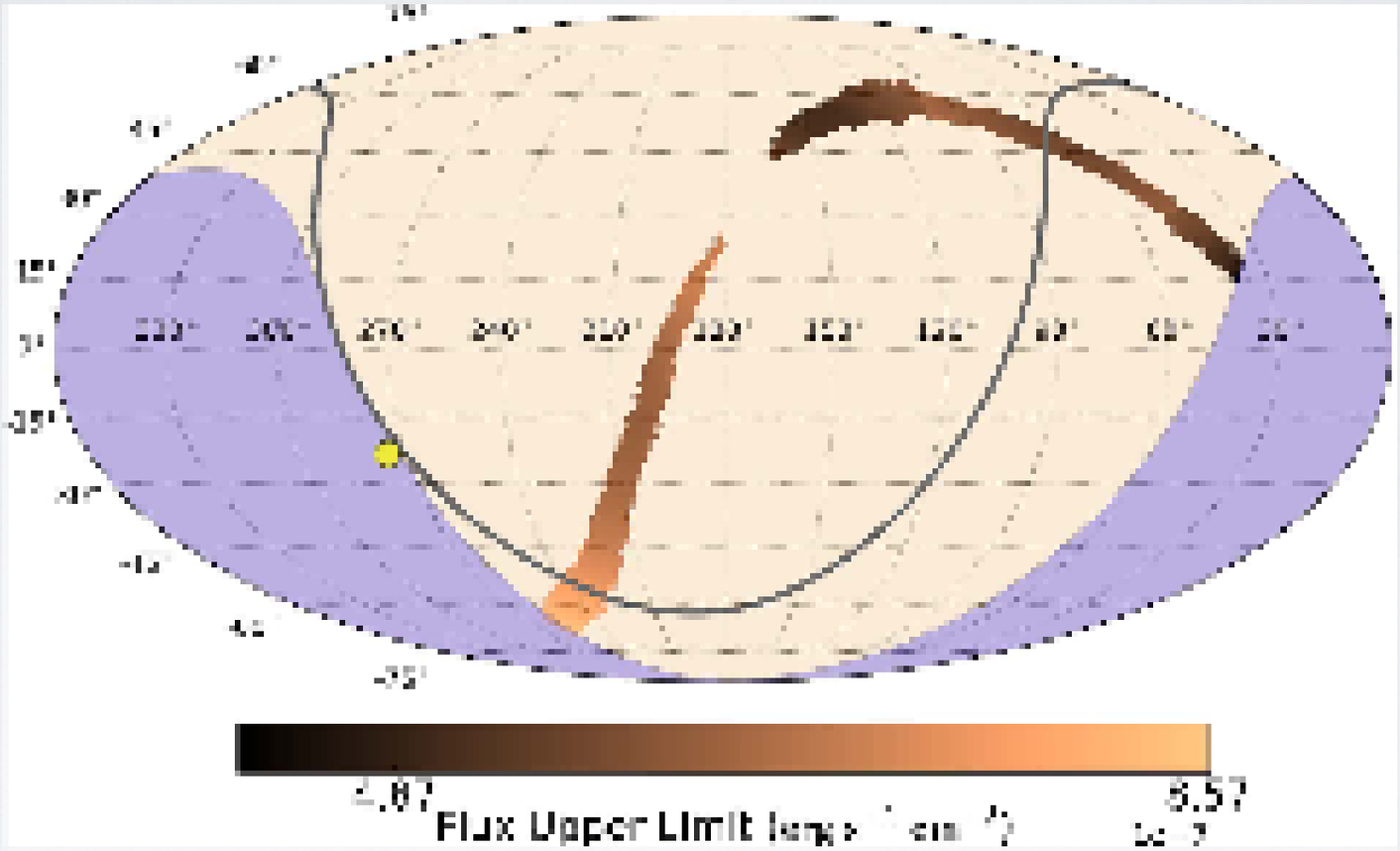


601 sq deg ➞ 199 sq deg

- Untriggered sub-threshold signal 0.4s after LIGO trigger.
- Consistent with a low-fluence short GRB coming from behind Fermi.
- Poorly localized but consistent with LIGO localization.
- 0.2% post-trials probability in statistical fluctuation.

Follow-up to Gravitational Wave Events

Racusin et al. ApJ 2017



- 3σ flux upper limit to GW151226 at 10—1000 keV, calculated from count rates +/- 30s of the GW trigger time.
  - Spectrum assumed to be cutoff power-law with Epeak = 566 keV and photon index of 0.42
- Based on provided location probability map, we cna calculate upper bounds on impulsive gamma-ray emission.

Follow-up to IceCube neutrino Events

- Utilizes all search methods:
  - On-board triggers.
  - Targeted search using event time.
  - Untargeted search within the hour.
  - Earth occultation technique.
- Good follow-up observation for IceCube-161103, upper limit published in GCN 20127.
- Other followup with limited GBM coverage: IceCube-170321A (GCN 20932).

Summary

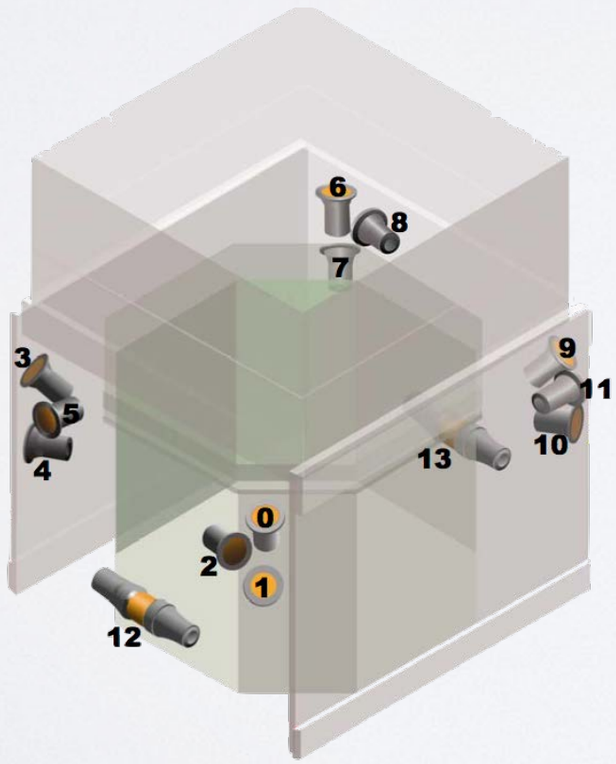
- GBM continues to be prolific in detecting GRBs and monitoring pulsars and Galactic transients.
- GCN notice of subthreshold GRB candidate events are now available.
- Continued development of offline data searches for joint detection of astrophysical transients with neutrinos and gravitational waves.

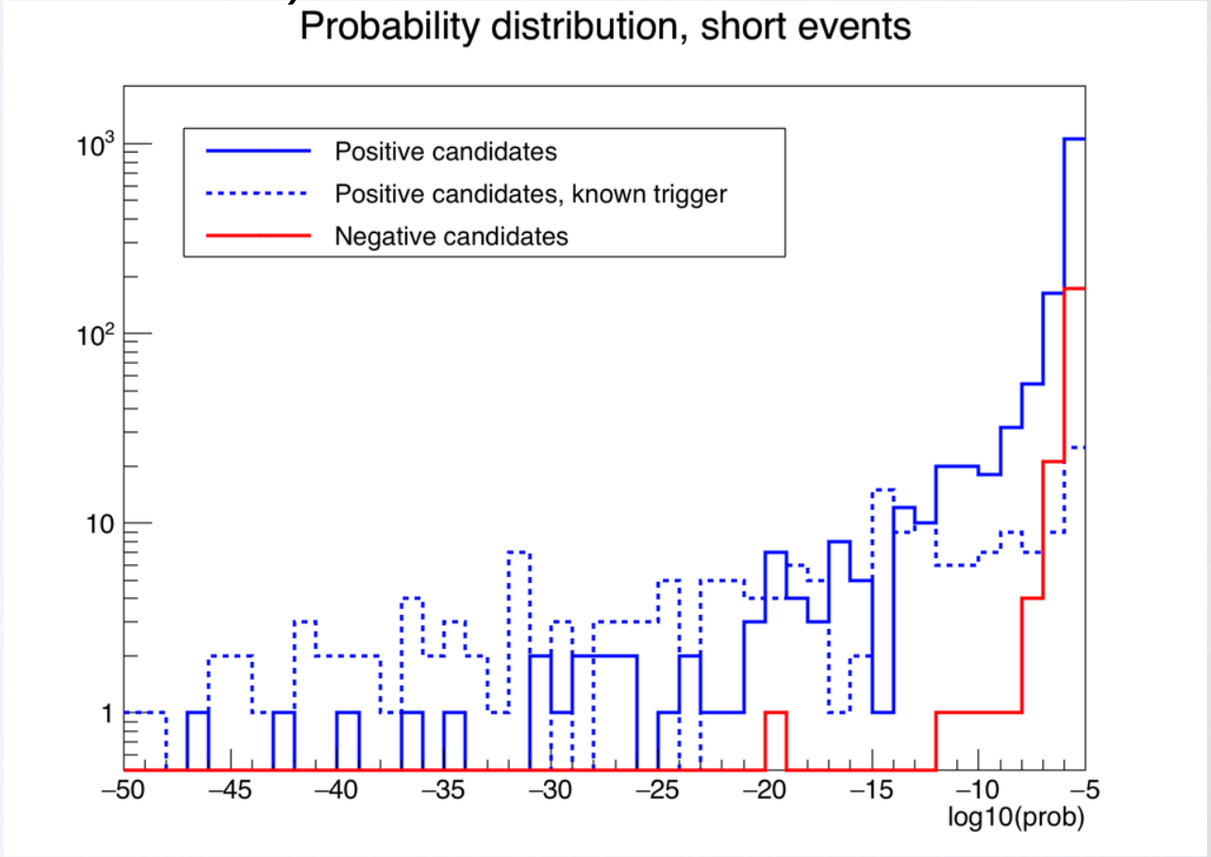
Back-up slides

GBM Untargeted Search

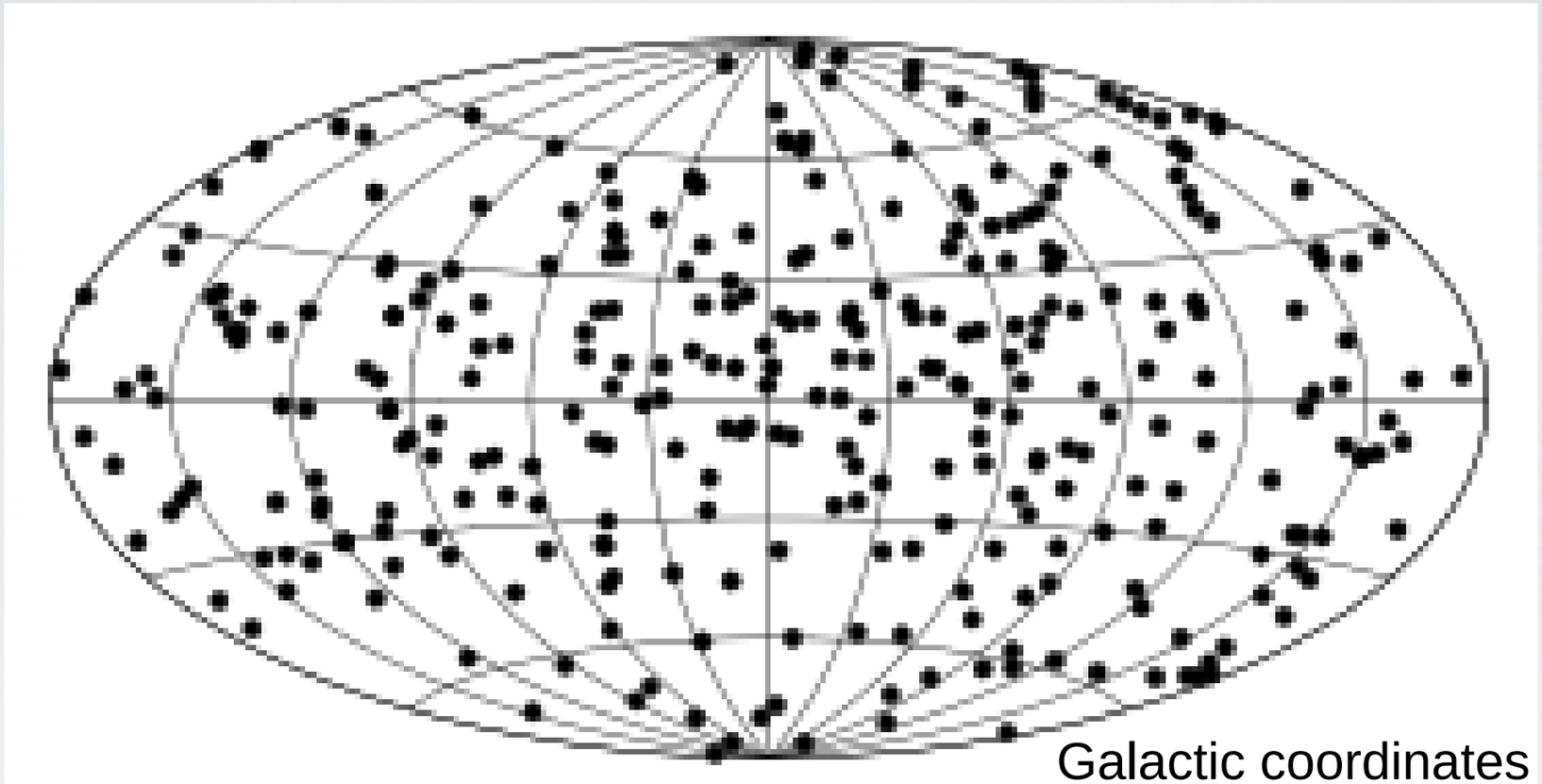
Untargeted search algorithms:

- Initially developed for Terrestrial Gamma-ray Flash search.
  - more details at http://fermi.gsfc.nasa.gov/ssc/data/access/gbm/tgf
- Using Continuous Time Tagged Events (CTTE) — 2μs time resolution with 128 energy channels.
- 2 detectors: 2.5σ and another 1.25σ above background.
  - one-day probability threshold <1e-6 for release.
  - Unfavorable geometry of the two above-threshold detectors are eliminated.
- 18 timescales — 0.064s to 32s.
- 4 energy ranges (optimized on GBM-triggered weak sGRBs).
  - 27—539 keV
  - 50—539 keV
  - 102—539 keV
  - 102—985 keV





GBM Untargeted Search

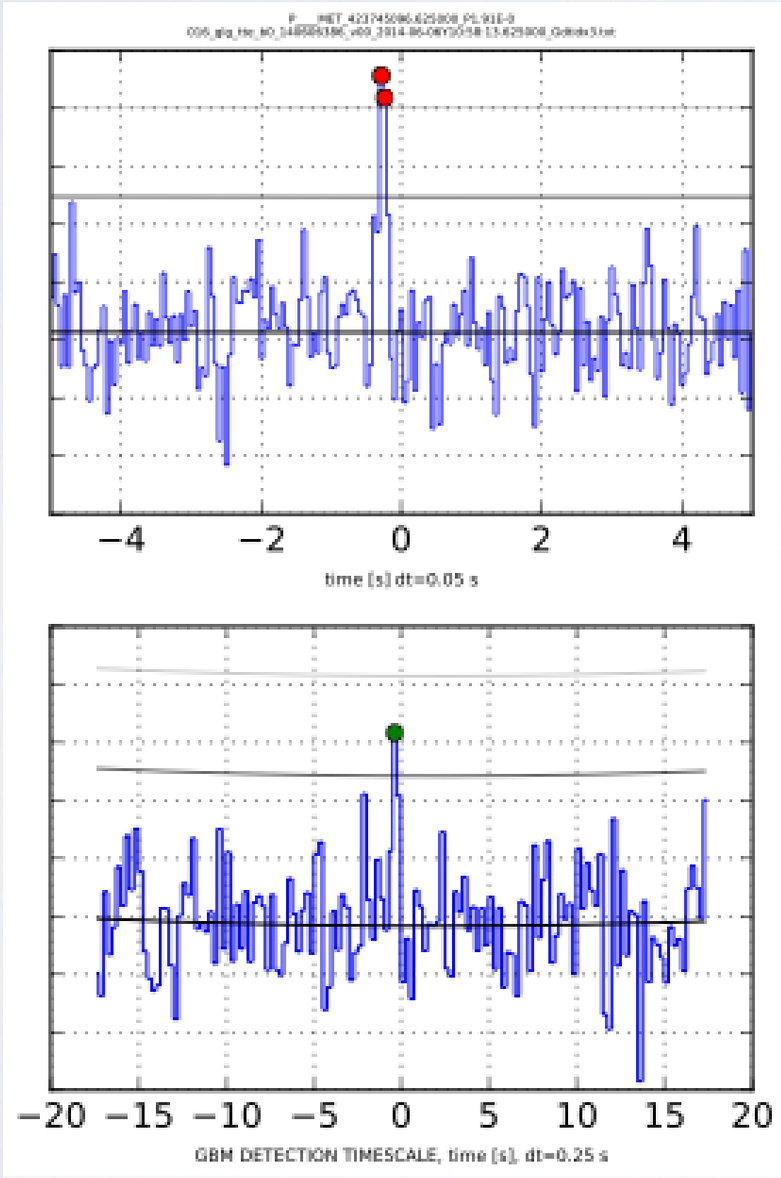


- 318 short, hard candidates found in 46 months.
  ➞ ~80 per year, twice the rate of GBM triggered short GRBs.

GBM Candidate Event

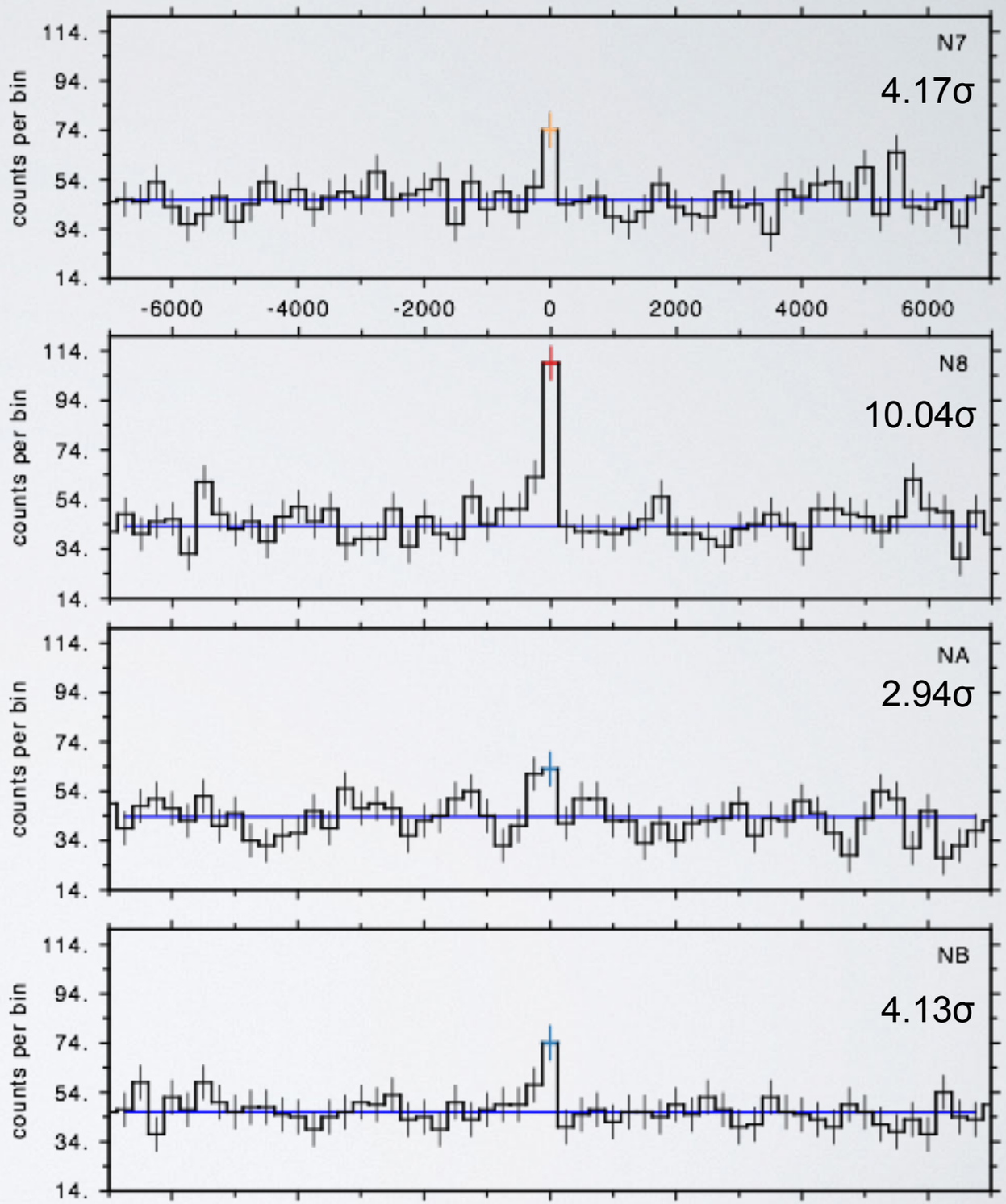
- 2014-06-06 10:58:13.625
- **Swift GRB 140606A**
- Found in 0.25s time binning
- 93 - 494 keV energy range
- P=1.91e-16

INTEGRAL ACS lightcurve



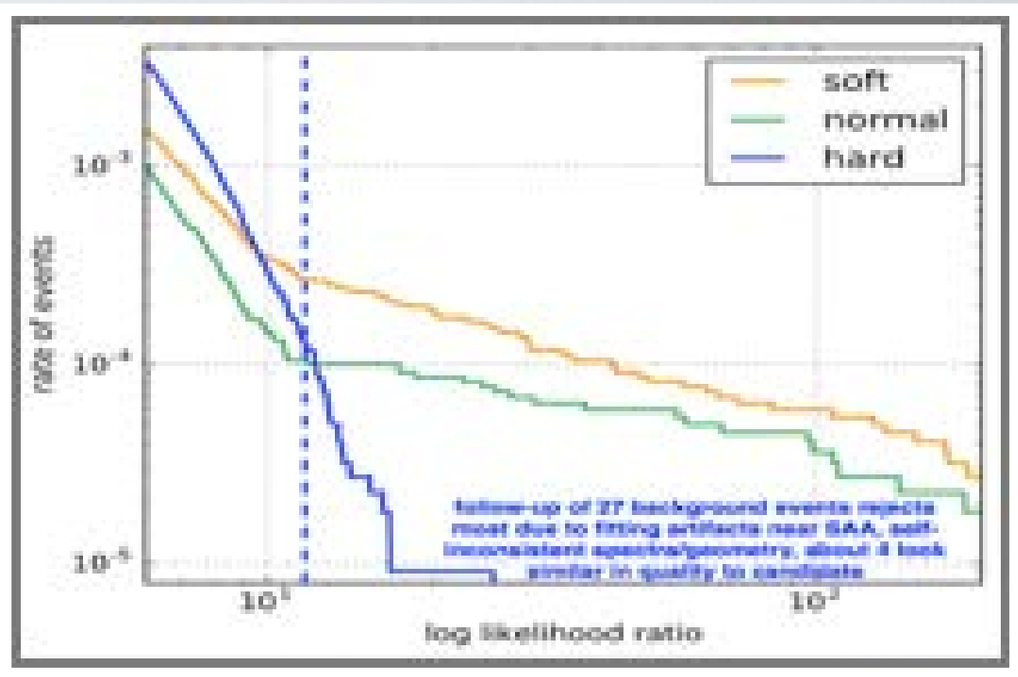
ACS native time bin

GBM timescale



False Alarm Probability Calculation

False Alarm Rate (FAR) = 27 hard events in 218821.1s of GBM live time, factor of 3 for spectra searched, 90% confidence.



$$P = 2 \times (4.79\text{e-}4\ \text{Hz}) \times 0.4\text{s} \times (1 + \ln(30\text{s} / 0.256\text{s})) = 0.0022$$

Offset in time in either direction.

Time offset between GW and GBM event start.

Effective trials factor for bins/durations searched